DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

SUMMARY

OF THE

PRIMARY TRIANGULATION

EXECUTED BY THE

UNITED STATES GEOLOGICAL SURVEY

BETWEEN THE YEARS 1882 AND 1894

BY

HENRY GANNETT
CHIEF TOPOGRAPHER

EXTRACT FROM THE SIXTEENTH ANNUAL REPORT OF THE SURVEY, 1894-95
PART I—DIRECTOR'S REPORT AND PAPERS OF A THEORETIC NATURE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1896

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Since the inception of topographic work by the United States Geological Survey in the spring of 1882, primary triangulation has been carried on upon an extensive scale, for the purpose of furnishing ultimate control for maps. To convey an idea of the magnitude of these triangulation operations, it may be stated that during these thirteen years no fewer than 1,295 primary points have been located, furnishing control for fully a half million square miles of country, or one-sixth of the area of the United States, excluding Alaska.

Since the primary purpose of this work has been to control maps upon scales not ordinarily exceeding 1 mile to 1 inch, the extreme of accuracy has not been sought, but only such degree of accuracy as would insure that no errors perceptible upon the scale of the map could accumulate.

Whatever work has been done by other organizations which is deemed to be of sufficient accuracy for the control of the maps of the United States Geological Survey has been utilized, both immediately for the control of topographic work and also for the extension of triangulation therefrom by the United States Geological Survey. The work of the United States Coast and Geodetic Survey has been largely used in this manner, especially in the eastern part of the country. The maps in New England, New York, New Jersey, and Pennsylvania rest in large part directly upon the triangulation of that organization, while in the Appalachian region triangulation has been extended by the United States Geological Survey from points determined by the United States Coast and Geodetic Survey in its great Appalachian belt. The work of the United States Lake Survey, and that of the New York State survey under Mr. J. T. Gardiner, have been extensively

utilized in a similar manner. In the interior of the country and in the far West, where no work by other organizations exists, primary triangulation has been done ab initio by the United States Geological Survey; astronomic determinations of positions have been made, base lines measured, and expansions effected by it.

As was stated above, 1,295 points have been determined by primary triangulation during the past thirteen years. These are distributed over thirty-three States and Territories, as appears from the following table, which gives the number determined in each State and Territory in which work has been done:

Maine	20	Michigan	7
New Hampshire	11	Arkansas	84
Vermont	1	Missouri	13
Massachusetts	13	Kansas	291
Rhode Island	12	Texas	236
Connecticut	16	South Dakota	19
New York	60	Montana	65
Pennsylvania	42	Wyoming	17
Maryland	5	Colorado	10
Virginia	44	New Mexico	32
West Virginia	32	Arizona	27
Kentucky	39	Utah	2
Tennessee	21	Nevada	12
North Carolina	23	Idaho	29
South Carolina	5	Oregon	4
Georgia	14	California	86
Alabama	3		

The methods and instruments employed in this work have developed as the work has progressed. This development has been in the direction of economy and efficiency as well as of accuracy, so that at the present time a much higher degree of accuracy is obtained than at the outset, together with a diminished expenditure upon field and office work.

In the early years of the work, base-lines were measured with secondary base bars. These were used up to the year 1887, when long steel tapes, 300 feet in length, under constant tension, were substituted, and have since been employed. They have been found more advantageous for the following reasons: The ground requires less preparation; the base can be measured much more rapidly, and, owing to the diminished number of contacts, with quite as great accuracy. By making the measurements upon cloudy days or at night, the correction for temperature is believed to be determined quite as accurately. Longer bases are measured, thus simplifying the expansion; and bases are measured more frequently, thus affording a greater number of checks upon the triangulation.

During the thirteen years in which this work has been going on, twelve base-lines have been measured in different parts of the country. Their

localities, the date and means of measurement, and their approximate lengths are set forth in the following table:

Base-lines measured by the United States Geological Survey.

Locality.	Year.	Means of measurement.	Length in miles.
Wingate, N. Mex	1881	Bars	4.20
Bozeman, Mont	1883	Bars	4.56
Austin, Tex	1884	Bars	6.40
Fort Smith, Ark	1887	Tape	2.84
Little Rock, Ark	1888	Tape	3.72
Spearville, Kans	1889	Tape	7.10
Albany, Tex	1889	Tape	9.00
Sierra Blanca, Tex	1890	Tape	4.60
Boise, Idaho	1890	Tape	4.75
Aspen, Colo	1891	Tape	1.00
Laramie, Wyo	1892	Tape	2.50
Rapid, S. Dak	1893	Tape	5.00

In early years the instruments used were vernier theodolites reading to 10 seconds, with circles 6, 7, 8, 10, and 11 inches in diameter. In 1889 there were substituted for these, 8-inch theodolites reading by microscope to 2 seconds, and these have since been employed universally in the primary triangulation.

While there is no question that the results from the instruments first used were amply accurate for the purpose, greater care was required in using them, a larger number of readings was necessary than with the present instruments, and the results were adjusted by least squares, which tedious operation is rendered unnecessary by the use of the better instruments. Indeed, it is believed that the instruments at present employed are of as high a grade as those in use in any part of the world, and that, by employing sharper signals, by exercising more care in the selection of times for observations, and by taking a larger number of measurements of angles than have heretofore been employed results can be obtained with them equal to the best secured in geodetic work.

The signals used differ with the facilities afforded by the neighborhood. The commonest form, and that which is generally in use in a settled country, is the ordinary tripod and pole, the tripod being swathed in cotton to facilitate finding it. In a wooded, unsettled region, tripods composed of three trees trimmed up are sometimes employed, or a single tree found upon the summit of a station is trimmed up and utilized as a signal. In the Rocky Mountain region a common signal is a cairn of stones upon a summit.

The permanent marks which have been left to indicate the stations also differ widely with the facilities afforded by the country for obtaining the necessary material. Of the total number of stations (1,295), 921 have been marked in a manner which may be regarded as permanent, 253 in a less permanent manner, while 121 have no mark of any degree of permanency. The permanent marks consist of copper bolts set in ledges, holes drilled in ledges, stone posts, buried bottles with

stones set over them, and cairns of stones, upon the largest of which inscriptions have been marked. Iron bolts and pipes set in the ground have been used. In many cases upon the plains section corners of the General Land Office surveys have been located, and in this case the section corner serves as the permanent mark. Buildings of various sorts also serve this purpose in numerous cases. Less permanent marks are marked trees, tripod signals, etc.

Triangulation has been carried on in the following areas in the years named:

New England, in the years 1887 to 1890, and in 1892.
New York and Pennsylvania, from 1889 to 1894.
Southern Appalachian region, from 1882 to 1890
Upper peninsula of Michigan, in 1889.
Arkansas, from 1887 to 1891.
Texas, from 1884 to 1893.
Kansas, from 1885 to 1887, and in 1889 and 1890.
Montana, in 1883 and 1884, 1886 to 1889, and in 1891.
Wyoming, in 1892.
Colorado, in 1893 and 1894.
New Mexico and Arizona, from 1882 to 1890.
Idaho, from 1889 to 1892.
California, from 1882 to 1893.
South Dakota, in 1891 and 1893.
Oregon, in 1894.

There has been expended upon this triangulation, including base measurement and expansion, and also all salaries and other expenses connected therewith, about $400,000, an average per year of $30,000, and an average per station located of a trifle over $300. The average expense of primary triangulation per square mile of area triangulated is about 80 cents. This item differs widely, however, in different parts of the country, being far greater in heavily timbered, level country, where the triangle sides are short and the expenses of clearing and signal-building heavy, while in the Rocky Mountains, when the triangle sides are long and when there is no clearing necessary, the cost is far below the above average.

As the simplest method of characterizing the degree of accuracy of this primary triangulation, the following table of average closure errors of triangles is presented. It is to be understood that in all cases the station adjustments and correction for spherical excess had been made prior to footing up these errors of closure. The work in Texas prior to 1887 and in other areas prior to 1889 was done with vernier theodolites, while the work in those and subsequent years was done with micrometer theodolites.

Closure errors of triangles.

Year.	Number of triangles.	Closure errors.	Year.	Number of triangles.	Closure errors.
Central Texas:			New Mexico:		
1884		8.50	1886	42	9.50
1886	40	7.77	1889 and 1890	29	10.00
1887	50	5.22	Montana:		
1888	14	8.08	Early years	48	19.10
1889	38	7.08	1891	74	3.39
1890	54	4.00	Kansas:		
1891	41	4.43	1885	62	7.95
1892	16	7.83	1886	30	15.80
1893	15	8.71	1889	71	3.49
Western Texas:			1890	*40	1.73
1892	36	9.85	1890	†62	2.07
California:			Arkansas:		
1886	34	18.86	1887–88	103	8.14
1887	9	13.46	1889	43	6.66
1889	24	6.93	1890	38	7.54
Arizona:			1891	48	9.18
1883	13	12.46			

* Spearville belt. † Northern belt.

The work in New England, New York, and Pennsylvania has been mainly supplementary to the work executed by the United States Coast and Geodetic Survey, and that in New York to the work of the United States Lake Survey and the New York State survey. In some places it has been found necessary to extend triangulation from the existing work of these organizations in order to furnish control for areas to be surveyed in other localities, and in certain cases the stations in preexisting work were too far apart to serve the purposes of the topographer, and it was therefore necessary to multiply stations within preexisting triangulation. The work done in these States by the United States Geological Survey is, therefore, not in compact bodies, but consists of a little work here and a little there.

The work in the Appalachian Mountain region south of Mason and Dixon's line is very extensive, spreading from the Blue Ridge westward across the valley and over most of the Cumberland Plateau. Its northern limit is Mason and Dixon's line, and its southern limit is the neighborhood of Atlanta, Ga., and Birmingham, Ala. This work rests upon stations of the United States Coast and Geodetic Survey along the Blue Ridge and the outlying ridges to the eastward, known as its Appalachian Belt. Most of the stations of the United States Coast and Geodetic Survey on the Blue Ridge from Maryland to Georgia have been occupied by the United States Geological Survey as initial points for triangulation. The work in this region has been done throughout with 6-inch and 7-inch vernier theodolites reading to 10 seconds, and has been subjected to least square figure and station adjustments.

A little triangulation has been done on the upper peninsula of Michigan for the purpose of controlling surveys of the Marquette iron district. This triangulation rests upon two stations of the United States Lake Survey, near Marquette.

The northwestern quarter of the State of Arkansas has been quite

well covered by triangulation. This was initiated by a base measured in the eastern part of Indian Territory, near Fort Smith, Ark., the site being a tangent of the St. Louis and San Francisco Railroad. The base is 2.84 miles in length. It was measured at night with a 300-foot steel tape. After expanding, triangulation was carried eastward to the neighborhood of Little Rock, opposite which, near Argenta, a second base, 3.72 miles long, was measured in a similar manner upon the roadbed of the St. Louis, Iron Mountain and Southern Railroad. The angles in the triangulation were measured with a 7-inch vernier theodolite reading to 10 seconds.

From stations in the eastern portion of this belt, work was extended northward across the Arkansas and over the Ozark Plateau to the Missouri boundary, thence returning southward near the west boundary of the State, and closing upon stations in the western part of the belt. Angles in this work were measured with an 8-inch micrometer theodolite.

The triangulation in Kansas is in three detached belts, each of which starts from a line of the transcontinental triangulation of the United States Coast and Geodetic Survey. The southern belt begins with the line Fulton-Hutton Mound, some 20 miles east of the Missouri-Kansas boundary, and proceeds nearly due west in a narrow belt of triangles and quadrilaterals until the Arkansas River is reached at Hutchinson; thence the general course of the river is followed as far as Larned, at which point the conditions favored a detour southwestward to Dodge, after which the river was followed to its present terminus, near Hartland.

The first part of this belt was executed in 1885 with a Gambey 11-inch vernier theodolite. In 1889 the belt was continued westward as far as Spearville with a Fauth 8-inch micrometer theodolite. At Spearville a base 7.1 miles in length was measured with a 300-foot steel tape, with a probable error of 0.39 of an inch. The next year work was resumed at Spearville and continued westward to the present terminus of the belt, at Hartland.

A second belt of triangulation was executed in 1886, work being based upon the United States Coast and Geodetic Survey line, Blue-Mound-Eckman, near Lawrence, Kans. This belt runs northwestward and then westward. Angles were measured with the Gambey 11-inch theodolite above referred to.

A third belt, lying west of that just described, uses for initial positions three stations of the United States Coast and Geodetic Survey, Blind Creek-Frey-Wilman. This belt first proceeds northward about 40 miles, and then takes a general westward course to its present terminus, near Leland, Kans. It consists of a series of well-proportioned quadrilaterals of larger size than the other two belts, the increase in size being rendered possible by more favorable topographic conditions. The instrument used was a Fauth 8-inch micrometer

theodolite. Angles were read by the method of direction, both singly and combined, in such manner as to give check observations on each angle which entered into the position. Adjustment by least squares was made in the earlier work, when vernier theodolites were employed; but in the later work, when better instruments were employed, it was considered unnecessary. Nearly all the signals consisted of tripods built of lumber. In connection with this triangulation a large number of section corners were located, usually by measuring directions and distances from the triangulation stations.

Triangulation has been carried on in Texas in two localities, namely, middle Texas, between longitudes 96° 30′ and 101°, and western, or trans-Pecos, Texas. The work in the latter section extends from the western point of the State as far eastward as longitude 103°, and from the Rio Grande to the New Mexican boundary line, inclosing an area of about 15,000 square miles.

The triangulation in middle Texas covers an area of about 50,000 square miles, nearly rectangular in shape. The work in this region was commenced in the neighborhood of Austin in the summer of 1884. A base-line 6.4 miles in length was measured with four-meter bars, and was connected with the astronomical determination of the United States Coast and Geodetic Survey at Austin. Work was carried on continuously until 1889, covering the area closely. In the latter year a verification base was measured near Albany, in the northern part of the State. This Albany base is about 9 miles in length, and was measured twice with a 300-foot steel tape under a tension of 20 pounds. The instruments used in the triangulation were 8-inch theodolites with verniers reading to 10 seconds, up to and including 1886, and during the remainder of the work an 11-inch theodolite reading by microscopes to single seconds was employed. The work done with the first-named instruments was adjusted by least squares; that subsequently done was not subjected to this adjustment. The signals were mainly tripods made from sawed lumber, with an interior scaffold for the support of the instrument whenever it was necessary to raise it from the ground.

In trans-Pecos Texas triangulation was commenced in the spring of 1890. A base-line was measured on the roadbed of the Texas and Pacific Railway, and an astronomic determination of position was made at Sierra Blanca. In this region the triangulation stations were usually the summits of sharp and well-defined mountain peaks, which were marked by piles of stones that served as signals.

Triangulation in the Black Hills of South Dakota originated in a base line in the valley of Box Elder Creek, about 4 miles northeast of Rapid. This base is nearly 5 miles in length and was measured with a 300-foot steel tape under a uniform tension of 20 pounds. The probable error of the measurement is 0.84 of an inch. The initial astronomic point is a pier in the county court-house at Rapid, the position of which was determined in 1890. The instrument used in the triangula-

tion was an 8-inch theodolite reading by microscopes to 2 seconds. The signals consisted of tripods of lumber with a signal pole in the center, under which the instrument was placed.

A little triangulation has been done in the Elk Mountains of Colorado for the control of a small area about Aspen. This work rests upon a base-line 1 mile in length measured along one of the streets of Aspen, and for astronomical position the work was connected with a station of the United States Coast and Geodetic Survey on Treasury Mountain. Angles were measured with an 8-inch vernier theodolite.

Triangulation in southern Wyoming rests upon a base-line about 2.5 miles in length measured along the roadbed of the Union Pacific Railroad just north of the town of Laramie. The initial position is an astronomical station in Laramie determined in 1872 by the Wheeler Survey. The instrument used in this triangulation was an 8-inch micrometer theodolite.

Triangulation in Montana covers an area of about 50,000 square miles. A base line located just west of the town of Bozeman, which was measured by officers of the Wheeler Survey in 1877 with a steel tape, was remeasured in 1883 by the United States Geological Survey with a secondary base apparatus. It was expanded and the work carried southward, to include the area of the Yellowstone National Park, during 1883 and 1884. In subsequent years the work was carried eastward, northward, and westward over much of central and western Montana. The angles were measured with an 8-inch vernier theodolite. In 1889 the triangulation was extended eastward down the valley of the Yellowstone to the neighborhood of Fort Custer, using an 8-inch micrometer theodolite.

Triangulation in Idaho covers an area of about 15,000 square miles, forming a parallelogram about 100 miles in breadth by 150 in length, extending from the longitude of Hailey on the east to the western boundary of the State. Work was begun in the summer of 1889 and continued until 1892, inclusive. It rests upon a base-line 1.75 miles in length measured near Boise with a 100-foot steel tape, and the resulting probable error of different measurements was 0.19 of a foot. The initial astronomic position is in the city of Boise. The instruments used in this triangulation were at first a 7-inch vernier theodolite, and during the seasons of 1891 and 1892 a 10-inch micrometer theodolite. The work done with the vernier theodolites was adjusted by least squares; that executed with the 10-inch theodolite was not subjected to this adjustment.

Triangulation in California, Nevada, and Oregon is in three distinct parts, which may be distinguished as the Cascade section, in northern California and southern Oregon; the Gold Belt section, including the Sierras in the latitude of Red Bluff, the Yosemite Valley, and from the Sacramento Valley eastward into Nevada; and the southern California section.

The work in the first section was begun in 1882 and continued until 1887. All distances, azimuths, and positions depend on the line Lassen-Shasta, as determined from unclosed triangles of the United States Coast and Geodetic Survey. The instrument used in this portion of the work was an 8-inch 10-second vernier theodolite. Natural points mainly were sighted, since sharp peaks were generally used. The work was adjusted by least squares.

In the Sierra Nevada, work was commenced in 1885. This work rests upon the line Marysville Butte-Pine Hill of the United States Coast and Geodetic Survey. Other lines determined by the same organization were used as check lines. During the first year the angles were measured with a 7-inch vernier theodolite. Subsequently work was done with similar instruments having an 8-inch circle. Upon most of the stations on this work signals were built, and in many cases these were very high and difficult to construct.

Triangulation in southern California was begun in 1891, and covers an area of about 5,000 square miles. The line Southeast Base-San Juan, as determined by the United States Coast and Geodetic Survey, serves as a base-line for this work. The instrument used was an 8-inch micrometer theodolite.

The triangulation in the plateau region of northern New Mexico and Arizona and parts of adjacent States depends on a base measured at Fort Wingate, N. Mex. This was measured in 1881 with four-meter bars, and was expanded and triangulation depending upon it was carried forward until 1890. The initial position, which is Fort Wingate, was located in 1883. The instrument used in the triangulation was a 10-inch vernier theodolite, prior to 1890, in which year an 8-inch micrometer theodolite was used. Many of the signals of this triangulation were natural points, consisting of high, sharp peaks. In other cases cairns of stone or trees were used. This triangulation, being carried on in a region of high mountains, consists of very large figures, lines of 100 miles in length being not uncommon. The area covered by this triangulation is approximately 94,000 square miles.

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